

BASALT VERSUS ANDESITE IN THE MARTIAN CRUST : NEW GEOCHEMICAL PERSPECTIVES.

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Introduction: Data from the *MGS* Thermal Emission Spectrometer (TES) has shown that surface type 1 (ST1) materials, interpreted as basalt, dominate the ancient crust in the southern highlands of Mars [1]. Large expanses of surface type 2 (ST2) materials in the northern lowlands have been variously interpreted as andesite [1, 2], oxidized crystalline basalt [3], or partly weathered basalt [4]. The ambiguity in interpreting the ST2 lithology arises because volcanic siliceous glass (a major component of andesite) is spectrally similar to some oxidation products and/or clay minerals in TES data. Distinguishing between these multiple working hypotheses is crucial to understanding the planet's crust composition and differentiation. This study offers new geochemical data that complement an earlier consideration of this problem [5].

One Size Fits All?: An important but often overlooked perspective is that a single interpretation of ST2 spectra may not be warranted everywhere on Mars (Ockam wasn't always right). THEMIS data from *Mars Odyssey* reveal adjacent volcanic flows of ST1 and ST2 materials emanating from the same caldera [6]. These flows have high thermal inertias and probably represent lava outcrops. For these units an igneous origin, involving successive eruptions of basaltic to andesitic lavas, offers a reasonable interpretation. For ST2 sediments, however, partly weathered basalt may be more likely. For example, [7] described deposits of ST1 sand dunes on the floors of large craters in Oxia Palus, adjacent to ST2 materials on the downwind side of the crater walls. In this case, ST2 is more plausibly explained as a weathered finer-grained fraction (containing some clays) winnowed by winds from coarser basaltic sediment on the crater floor. If oxidized basalt particles are fine grained, they too might be winnowed and concentrated on crater walls.

Materials of the Northern Plains: In evaluating the bulk composition of the martian crust, we must focus on interpreting global-scale deposits of ST2 materials in the northern plains. These plains, mapped as the Vastitas Borealis Formation (VBF), have recently been interpreted as sedimentary deposits derived from outside the basin [8] or altered sediments formed through local reworking of earlier deposits by permafrost processes [9]. The ST2 sediments are underlain by ancient ridged plains interpreted as volcanic flows. A few local SF1 deposits identified in northern plains

impact craters have been interpreted as ancient underlying materials possibly excavated by impact [10]. TES spectra of the Vastitas Borealis boundary in southern Acidalia Planitia, where it is not obscured by dust, indicate that the proportion of ST1 (basalt) material increases outside the basin [7]. Both of the VBF "new-view" theories [8, 9] propose these materials have undergone significant reworking by either transport and/or indigenous weathering and may support alteration of basaltic sands within this depocenter.

Methods: Although TES is a mineralogical tool, bulk rock geochemistry can be derived from deconvolved modal mineralogies by combining the compositions (wt. % oxides) of spectral endmembers in proportion to their relative modes [11, 2]. We have estimated ST1 and ST2 chemical compositions from deconvolutions derived using modified spectral endmember sets of [1, 2, 4, 12]. The spectral endmember sets include a range of igneous and sedimentary minerals and the fitting was constrained to the 1301 to 233 cm⁻¹ region (prior studies used 1280 to 400 cm⁻¹). To facilitate comparisons with other data sets, these compositions are calculated on a water- and CO₂-free basis.

Geochemical Interpretation: There is surprisingly little difference between bulk compositions for ST1 and ST2 using different endmember sets. ST1 compositions plot within the basaltic andesite field and ST2 compositions in the andesite field on an alkali-silica classification diagram for volcanic rocks (Fig. 1). However, with error bars [2, 11], both ST1 and ST2 compositions mix across the basaltic andesite – andesite fields and are less distinguishable. Both ST1 and ST2 are distinct from SNCs while ST2 compositions plot near the *Mars Pathfinder* dust-free, water-free, rock composition (in Fig. 1, but not necessarily in other diagrams). It is notable that all ST2 modeled mineralogies contain more clays and/or weathering products compared to ST1. These phases result in higher values for silica when normalized chemistries are calculated on a water- and CO₂-free basis and can cause errors when using igneous classification schemes. Prior to normalization, the range of ST1 and ST2 chemistries differ by only 1.5 to 3.0 wt.% SiO₂ and are all classified as basaltic andesite. Recently, *Mars Pathfinder* rocks have been suggested to have high water contents (~2 wt% H₂O) and lower silica abundances (~49%

SiO₂) than previously reported (~58% SiO₂), suggesting that the rocks may be weathered [13].

If ST2 is andesite, we can explore its relationship using Fig. 2. On Earth, igneous rock compositions like ST2 are calc-alkaline andesites found exclusively in subduction zone settings. ST2 compositions lie on a terrestrial calc-alkaline trend produced by fractionation of basaltic andesite magma containing water. ST1 lavas have compositions similar to the primitive basaltic andesites found in subduction zone environments [14].

The positions of fractionation paths in Fig. 2 (small arrows, constrained from experiments on melts containing 6% water) are controlled by initial liquids produced by high extents of melting of refractory mantle under hydrous conditions (heavy arrow). The melts are in equilibrium with a refractory harzburgite source and contain high H₂O contents (4-6 wt. %). High H₂O contents are essential in producing the high SiO₂ and low FeO*/MgO by mantle melting. Anhydrous melts of the terrestrial mantle would plot at lower SiO₂ and higher FeO*/MgO within the tholeiitic (TH) field.

Figure 2 suggests that andesite with ST2 composition might have formed by fractional crystallization under hydrous conditions of a ST1 basaltic andesite parent magma. The required H₂O is intriguing because such high contents are typically found only in terrestrial subduction zone environments and are in contrast with predicted martian mantle volatile contents.

We can explore ST2 as a partly weathered basalt using Fig. 3, in which arrows illustrate the effects of chemical weathering of basalts [15]. The diagram shows that weathering of ST1 could produce sediments with ST2 composition. Neither surface type is compositionally similar to basaltic shergottites or the global dust [16]. Chemical weathering of ST1 or ST2 should not produce the global dust composition, but the dust might form by addition of iron-oxides to ST2. The *Mars Pathfinder* dust-free, volatile-free, rock composition is similar to ST1 in one diagram, but not in the other.

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Fig. 1. Chemical classification diagram for volcanic rocks, showing TES-derived compositions for Mars.

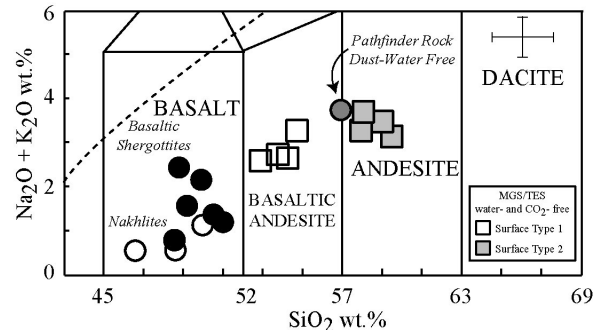


Fig. 2. Diagram illustrating how andesite forms through partial melting of mantle peridotite, followed by hydrous fractional crystallization.

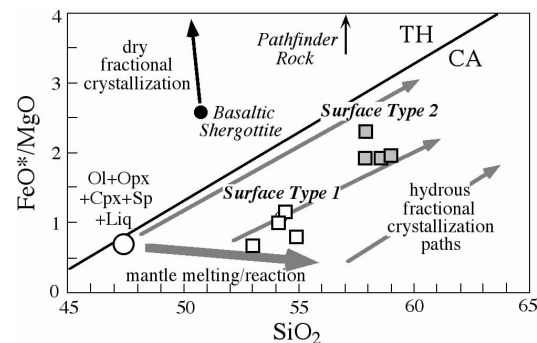


Fig. 3. Molar chemical weathering trends in basalts, showing that ST2 could form by weathering of ST1.

